Electron-ion effects at transition -- an obstacle on the upgrade path

J. Wei, U. Iriso, M. Bai, M. Blaskiewicz, P. Cameron, R. Connolly, A. Della Penna, W. Fischer, H. Huang, R. Lee, R. Michnoff, V. Ptitsin, T. Roser, T. Satogata, S. Tepikian, L. Wang, S.Y. Zhang

RHIC Retreat 2005

June 15 - 17, 2005

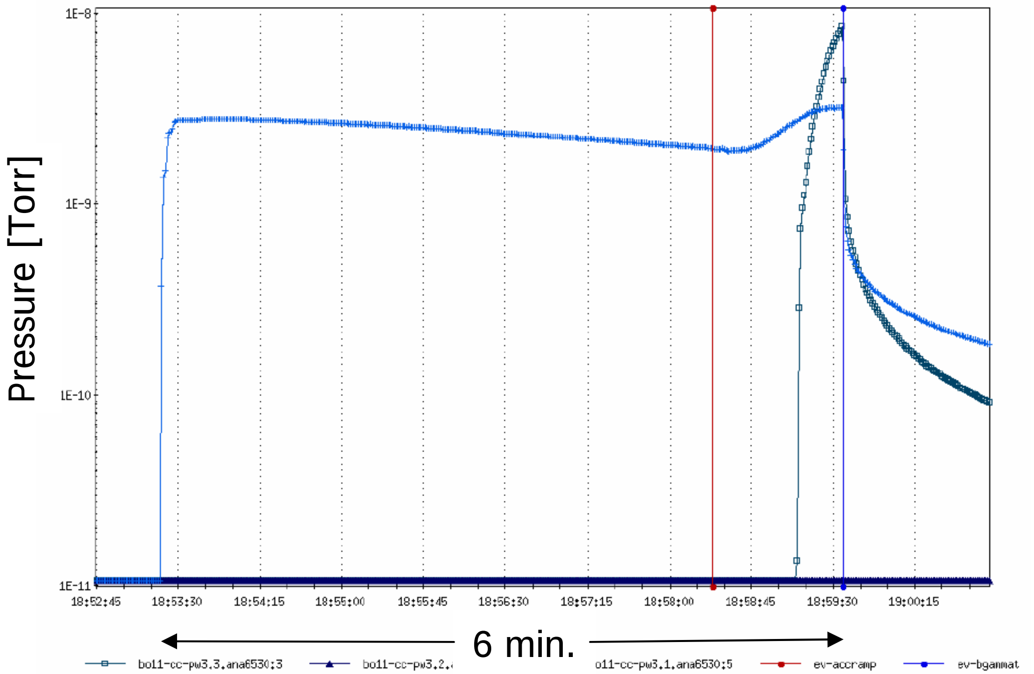
BROOKHAVEN NATIONAL LABORATORY

Outline

- Mechanism
  - Electron cloud formation & electron-ion interaction
  - Single-, long bunch vs. multiple, short bunch regime
- Observations
  - Bunch-train dependence of loss, emittance
  - Trailing-edge phenomena
- Mitigation schemes
  - NEG coating
  - RF manipulation
- Discussions

Phenomena

- Electron-cloud formation
  - Vacuum pressure rise
  - Electron flux
  - > Occurs when the peak beam current is high (near transition, common IR area)
- Electron-ion interaction
  - Beam loss
  - Transverse instability
  - Transverse emittance growth
  - Longitudinal profile variation
  - Tune shift
  - > Significant at transition, lack of Landau damping



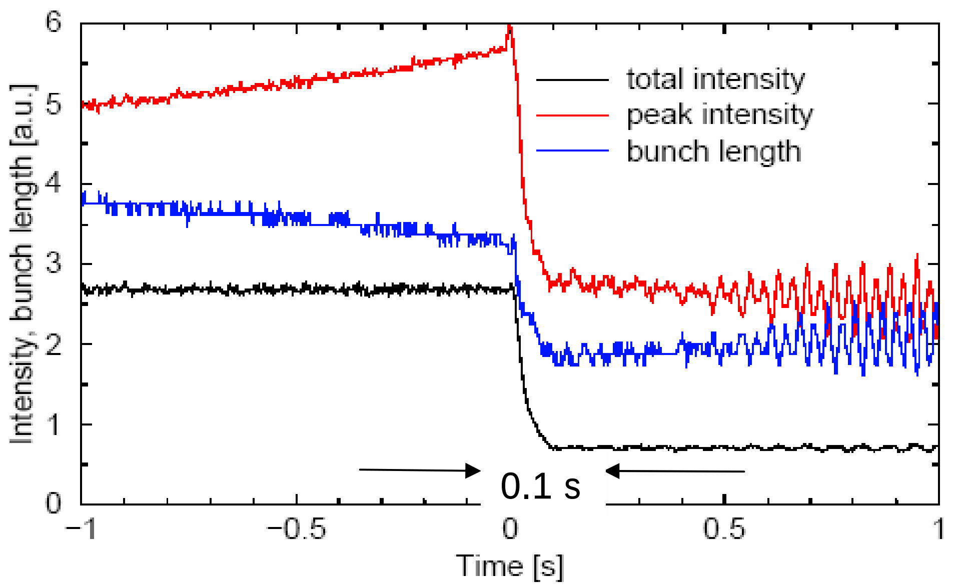
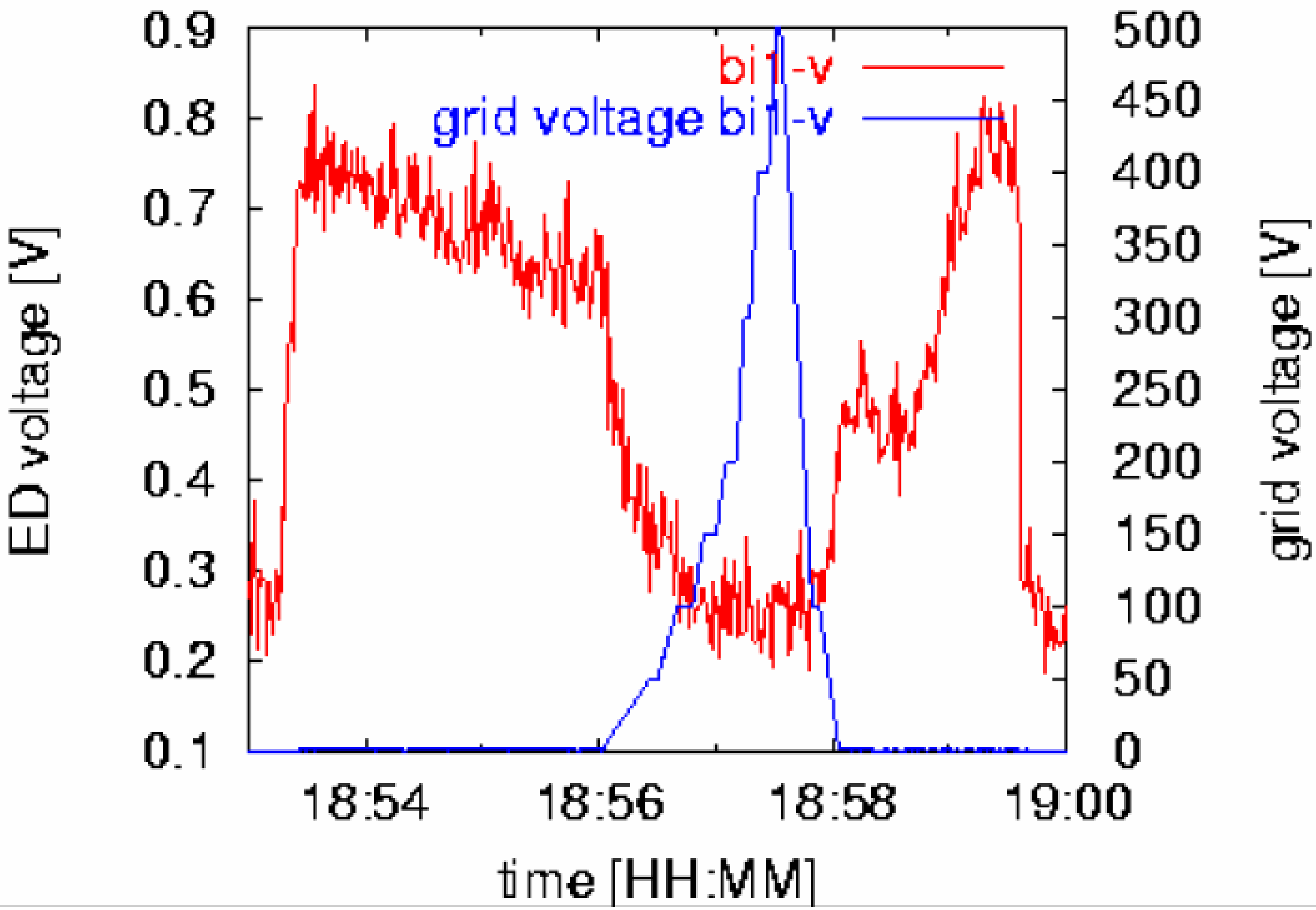


Figure 2: Beam loss and bunch size variation of bunch #40 at transition with $V_{rf} = 300$ kV and $b_{oct} = -3$ unit.

Correlation between e-flux and pressure

- Voltage sweeping to set baseline before ramping



BROOKHAVEN NATIONAL LABORATORY

Is it electron?

- Measured electron flux that correlates to pressure and bunch-train dependence of beam loss
- Bunch-train dependence of beam loss, emittance growth, instability growth
- Trailing-edge beam loss

➢ A definitive measurement would be tune shift along the bunch train
  - ➢ Previously measured at injection

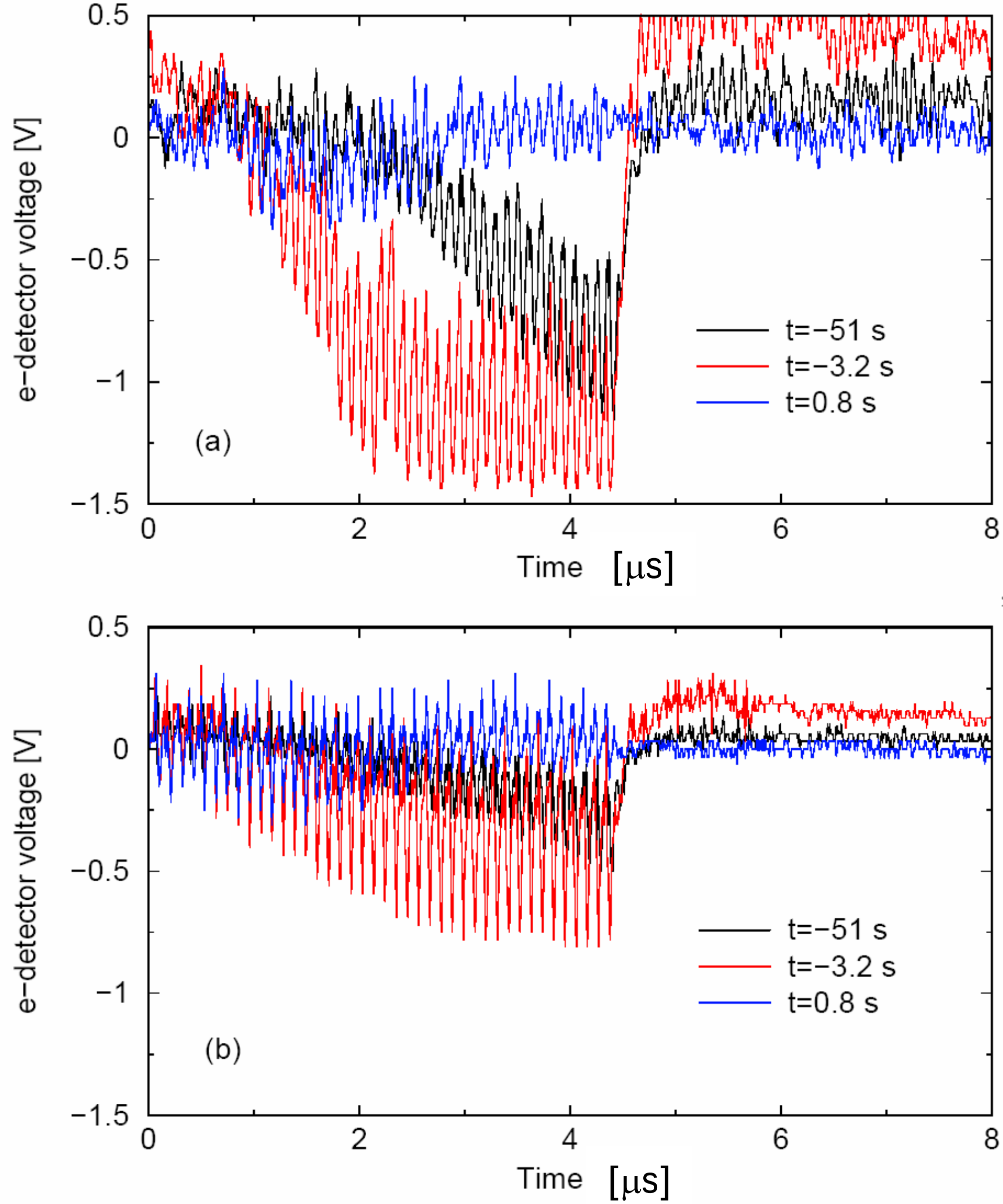
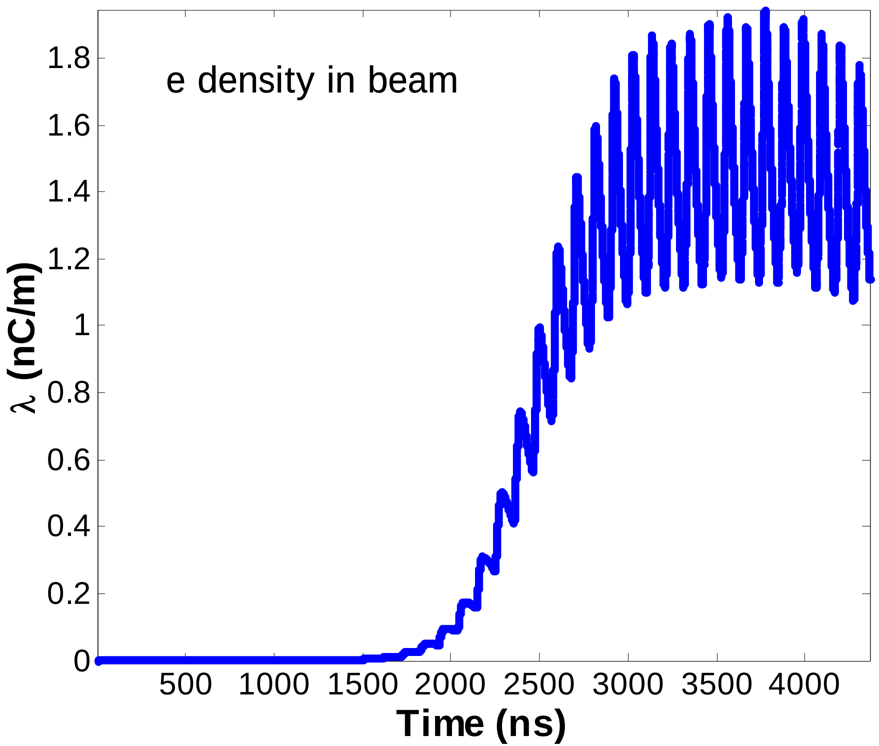
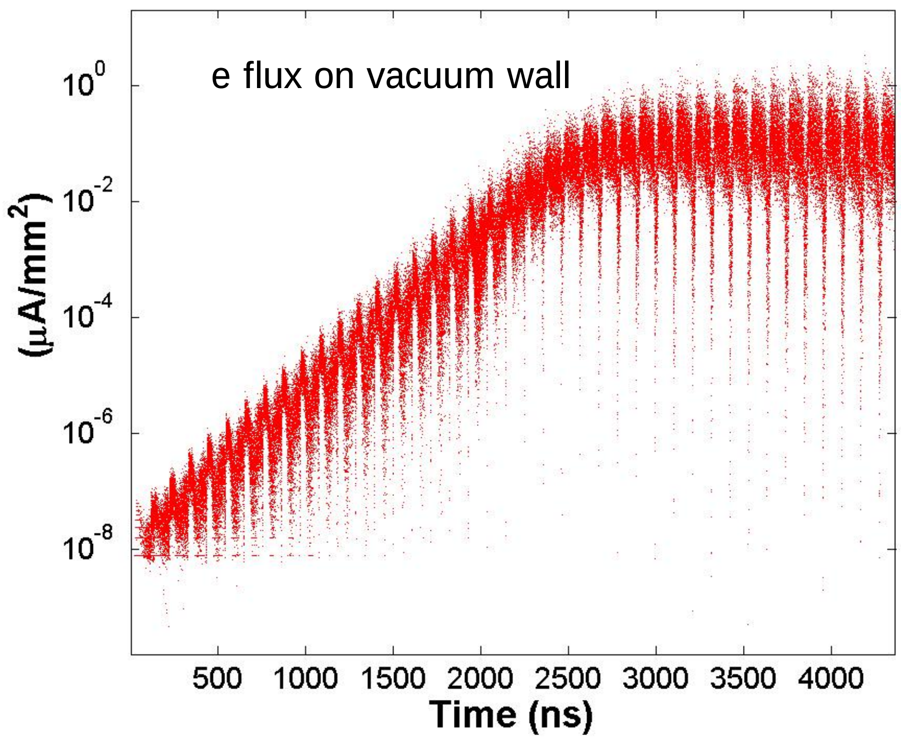


Figure 10: e-flux measured in the (a) horizontal and (b) vertical directions near γ_T. An ac-coupled amplifier is used with a low-frequency cut-off of about 300 kHz. The grid is not biased. The collector is biased at 50 - 100 V positive.

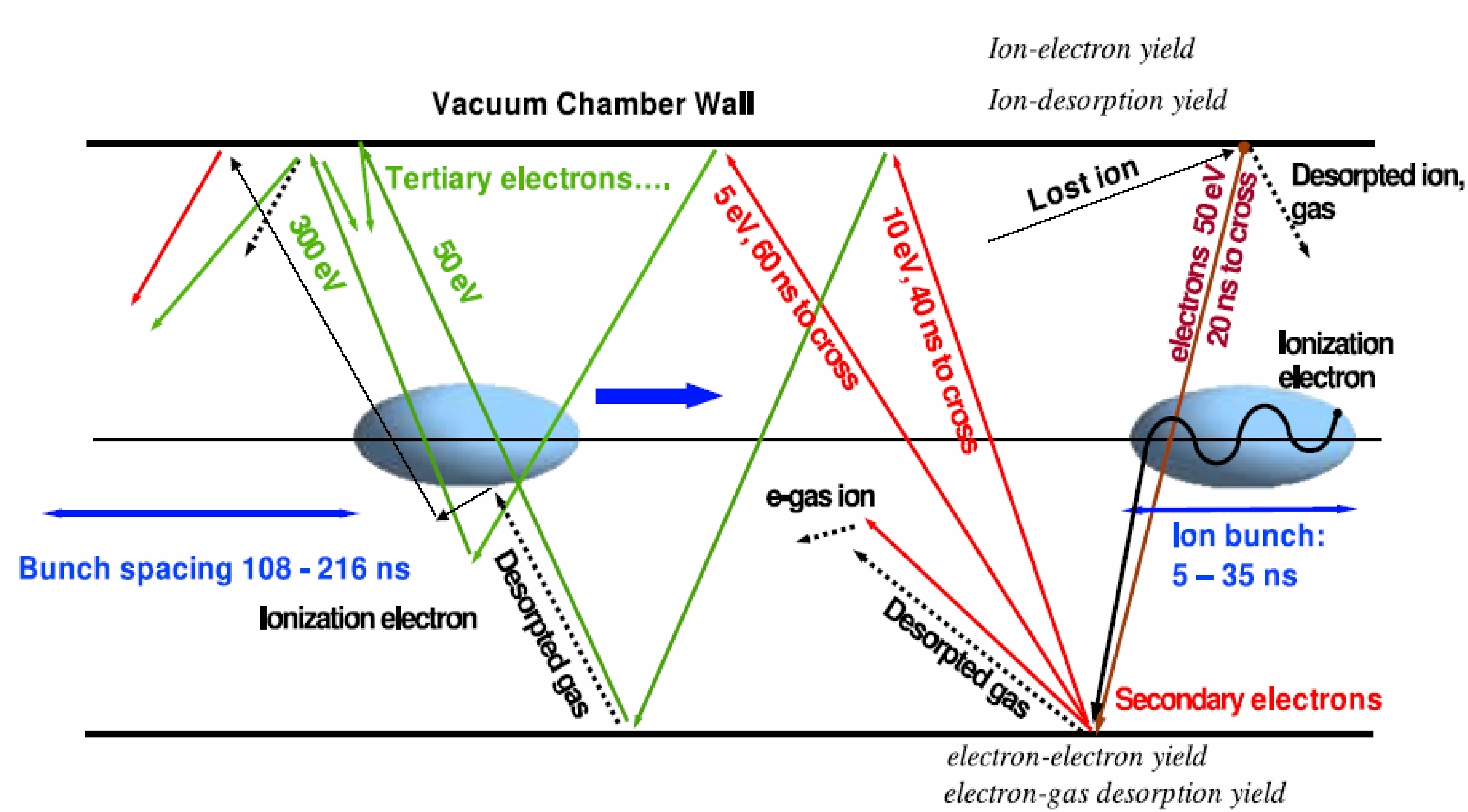
CLOUDLAND simulation (L. Wang)

- Simulation of “realistic” condition with peak secondary yield near 1.8, and non-zero yield at zero energy
- Electron build-up along the beam bunch train
- “Easily” reproduces electron flux observations regarding electron build-up and saturation





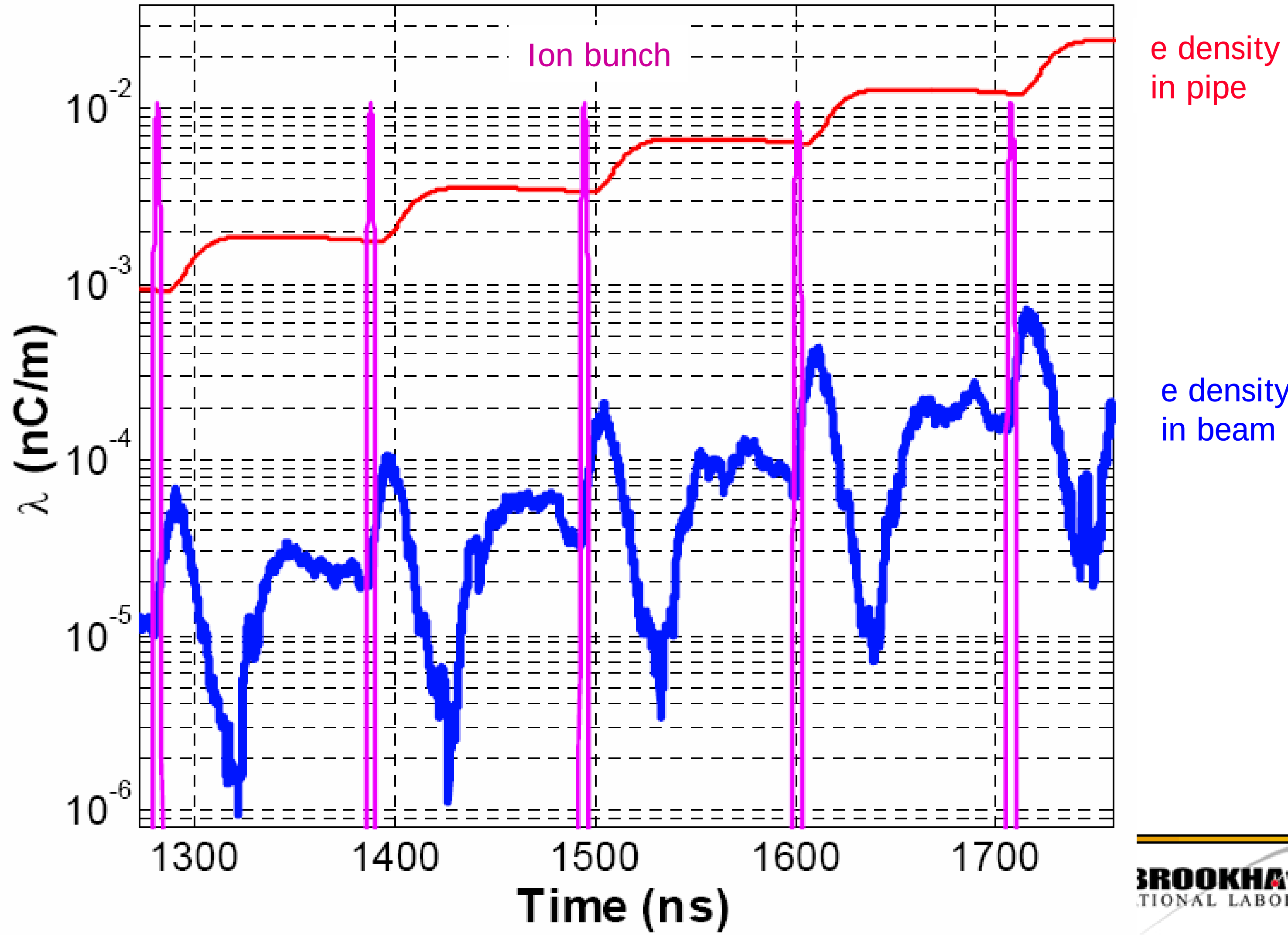
Beam-driven electron multipacting



BROOKHAVEN NATIONAL LABORATORY

Simulation: multi- & single bunch effects

- 3 times higher electron density at the tail than that at the head of the ion bunch



(L. Wang)

e-cloud parameter regime (2005)

- Single beam (blue), up to 41 bunches, 3-bucket, 108 ns spacing
- Cu, 5×10^9 per bunch; varying RF voltage and octupole strength

Table 1: RHIC parameters during year 2005 e-I study.

Ring revolution period	12.79	μs
Aperture, IR (2/6/8/10, 4/12)	7, 12	cm
Aperture (arc, triplet)	7, 13	cm
Beam species	Cu^{29+}	
Energy, injection - top	9.8 - 100	GeV/u
Transition energy, γ_T	22.9	
Bunch intensity	5×10^9	
Bunch center spacing	108	ns
Bunch length at transition, full	~ 5	ns
Electron bounce frequency	~ 400	MHz
Peak bunch potential	~ 1.6	kV
e^- energy gain upon acceleration	~ 300	V

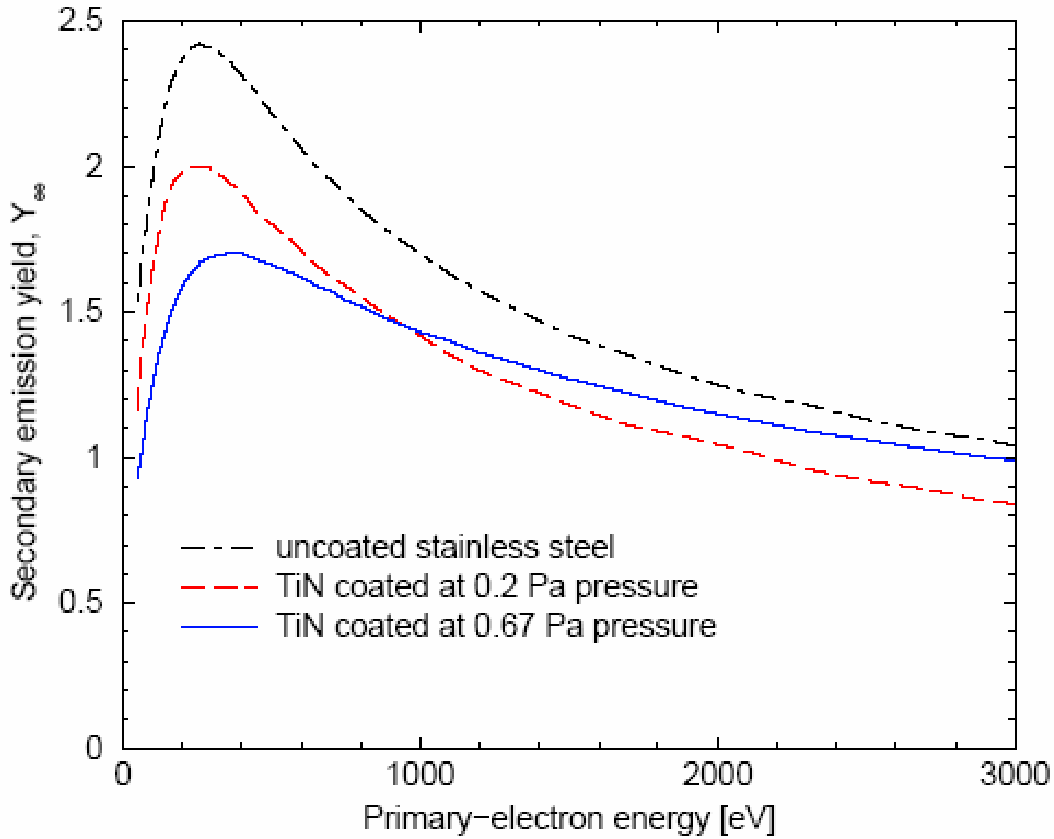
e-cloud multipacting mechanism

- Intermediate-regime multipacting condition:

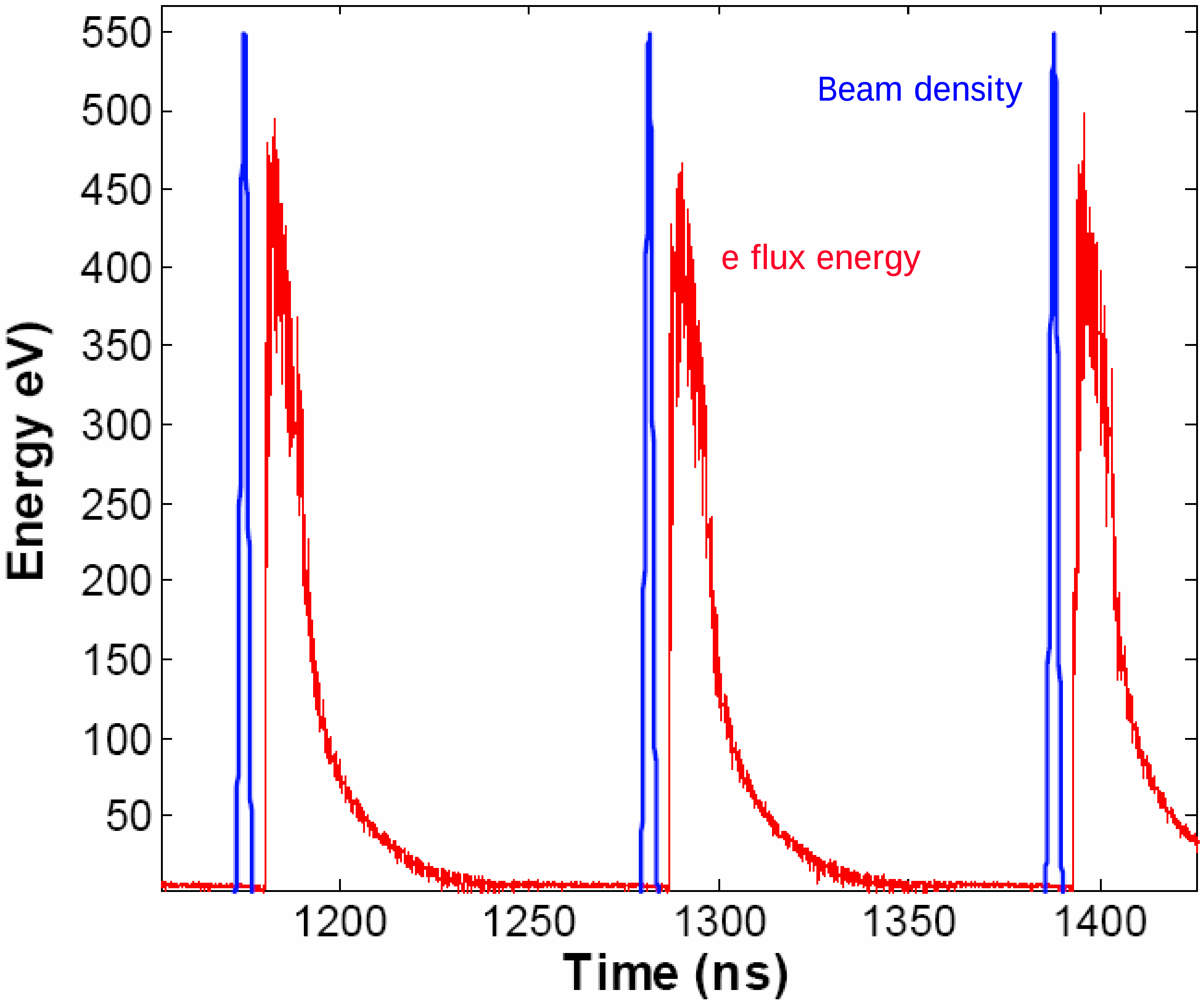
$$Y_{ee,C} \equiv \Pi_{i=0,1,\ldots,N_{ee}} Y_{ee,i} > 1$$

where

$$Y_{ee,0} > 1, \ \text{and} \ Y_{ee,i} < 1 \text{ for } i = 1, \ldots, N_{ee}$$



Electron energy & SEY (simulation)



(L. Wang)

Beam loss vs. bunch sequence

- Puzzle: why the first-bunch beam loss is much higher than nominal, 216 ns spacing case?

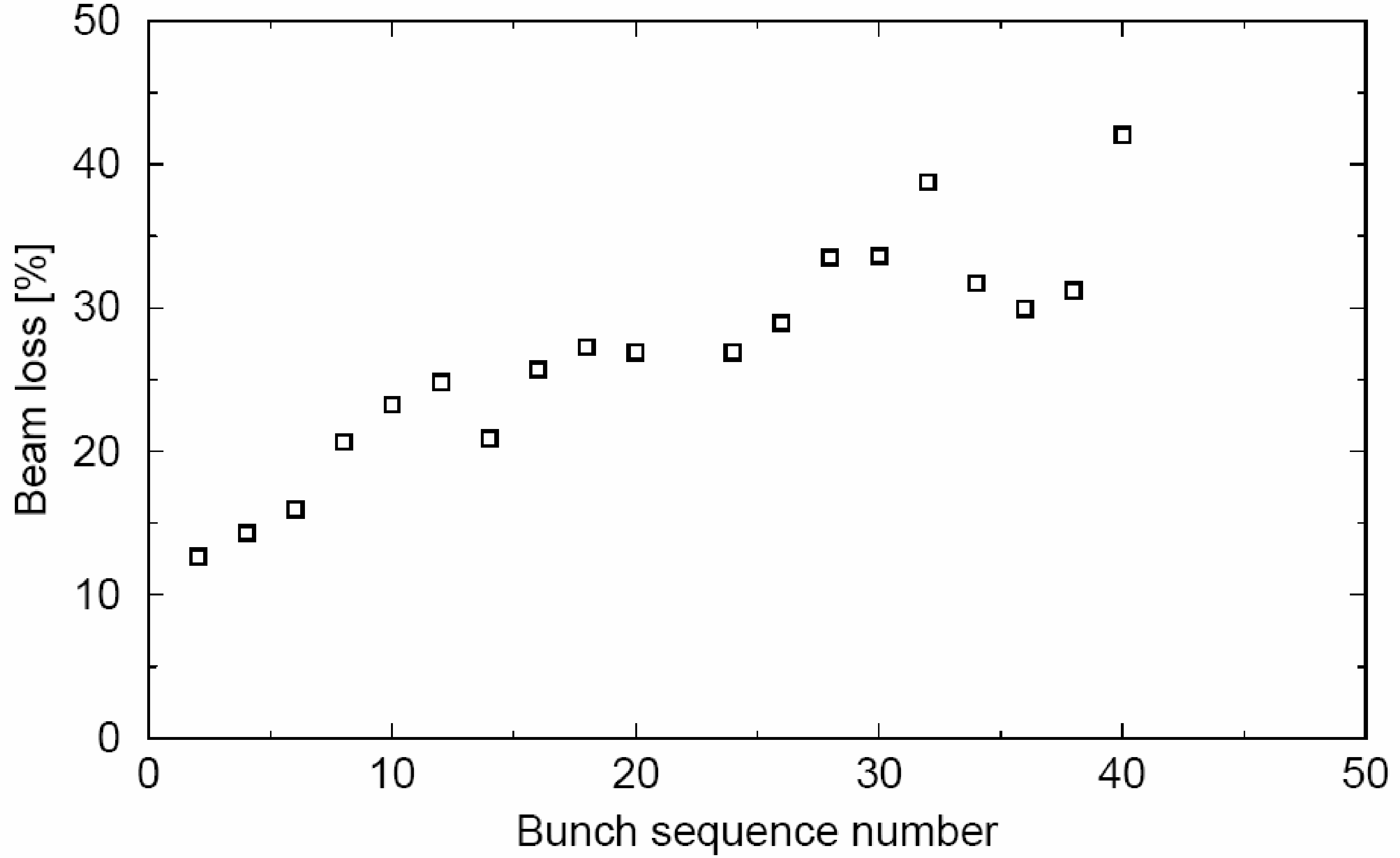
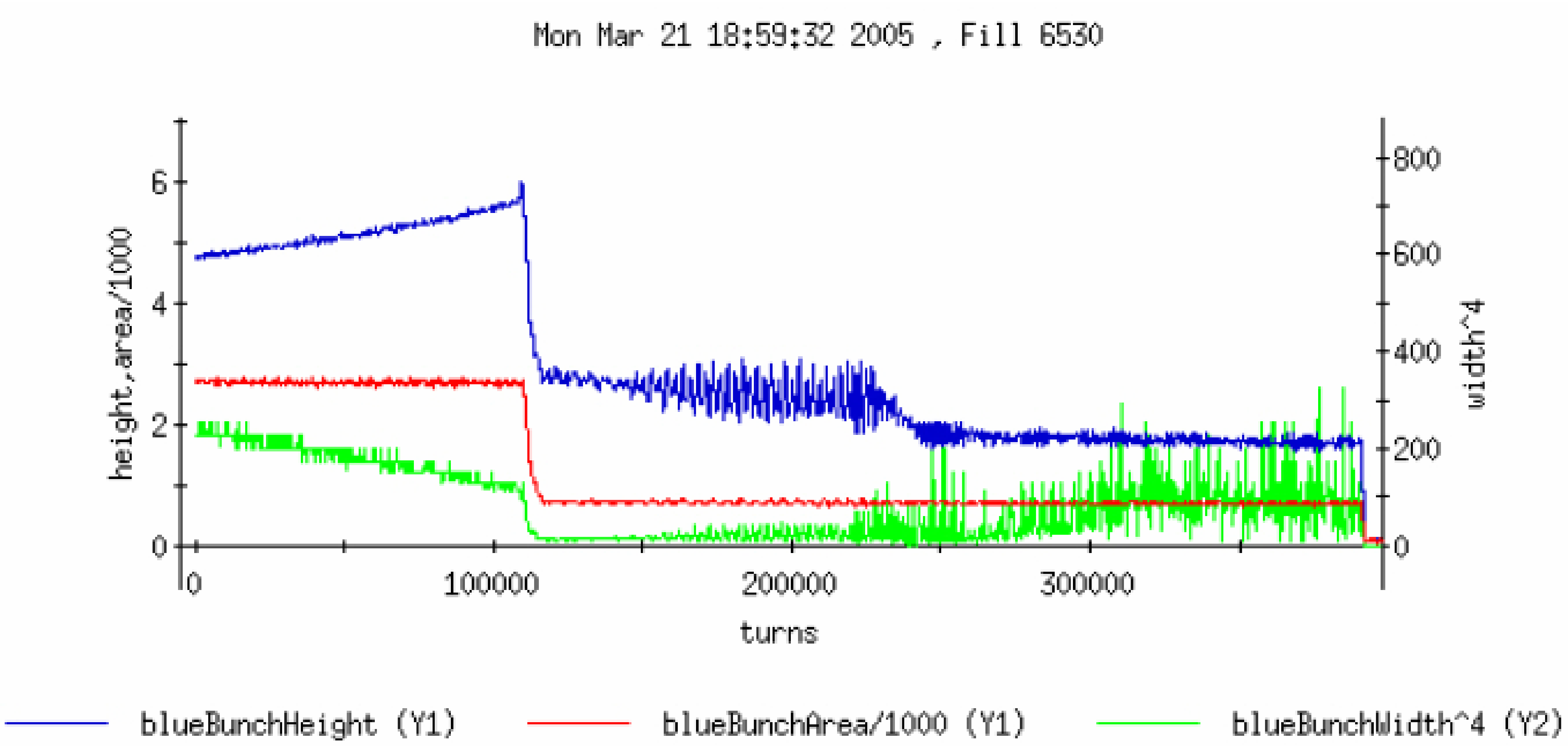


Figure 3: Beam loss at transition as a function of bunch sequence number with V_{rf}=200 kV and $b_{oct} = -3$ unit.

#6530 WCM of bunch #40

- Tracked one bunch across transition every 250 turns
  - Beam loss: 73% on bunch #40; 52% averaging over 41 bunches



Instability seen by coherence monitor

- Transverse instability occurs about 10 ms after transition for about 100 ms

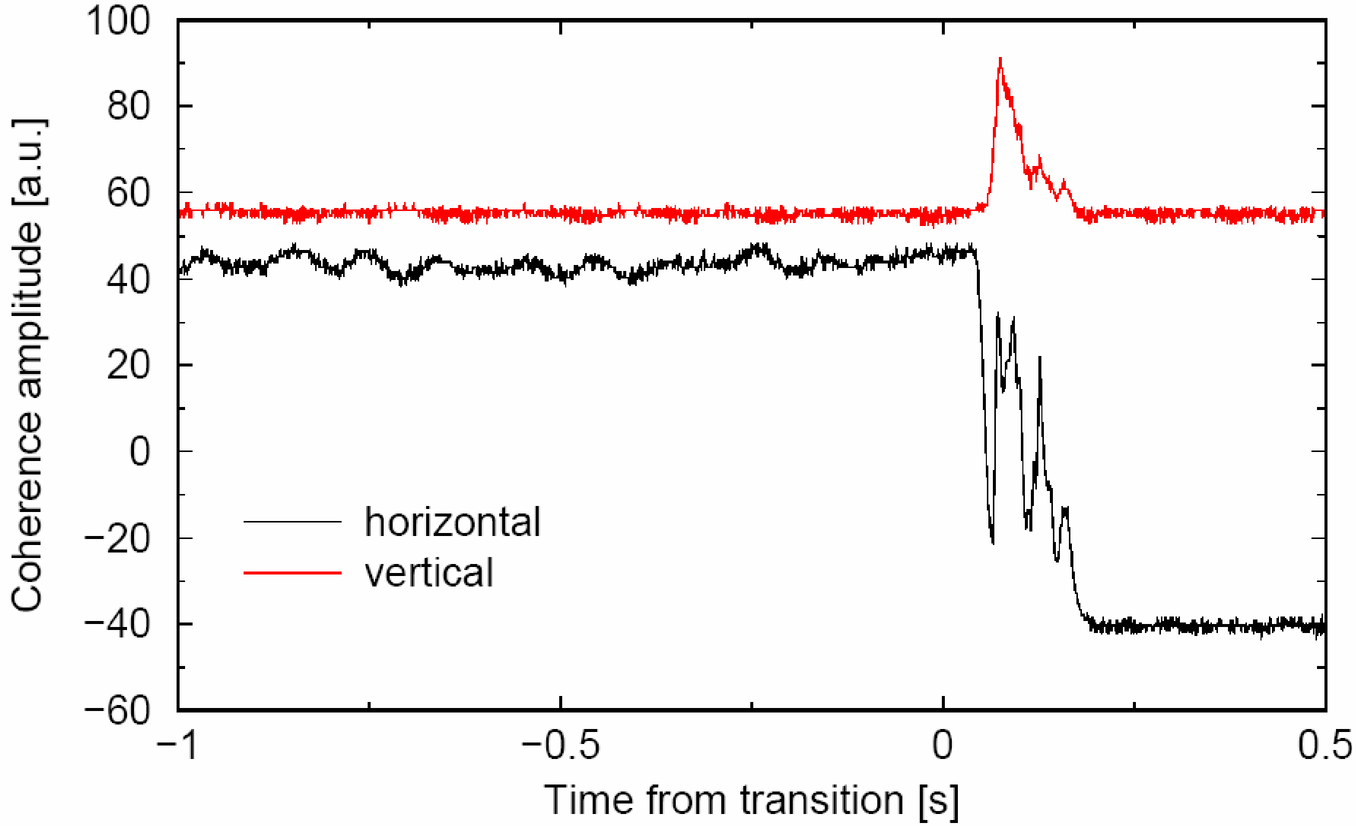
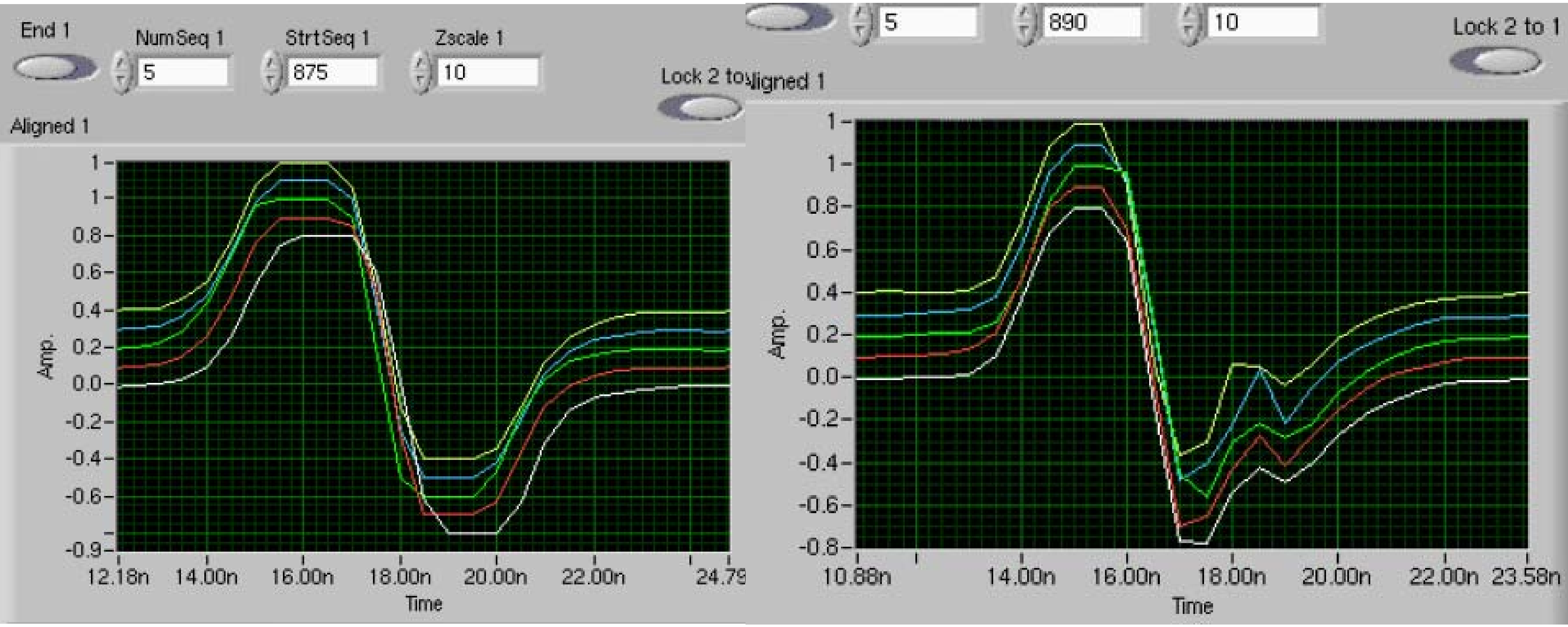


Figure 5: Coherence signal of bunch #40 from the turn-by-turn BPM data. The horizontal instability signal is within a step caused by the orbit shift due to γ_T-jump.

Button BPM (1)

- Trailing edge structure starts about 10 ms after transition, lasts for about 50 ms
- Time scale corresponds to WCM's

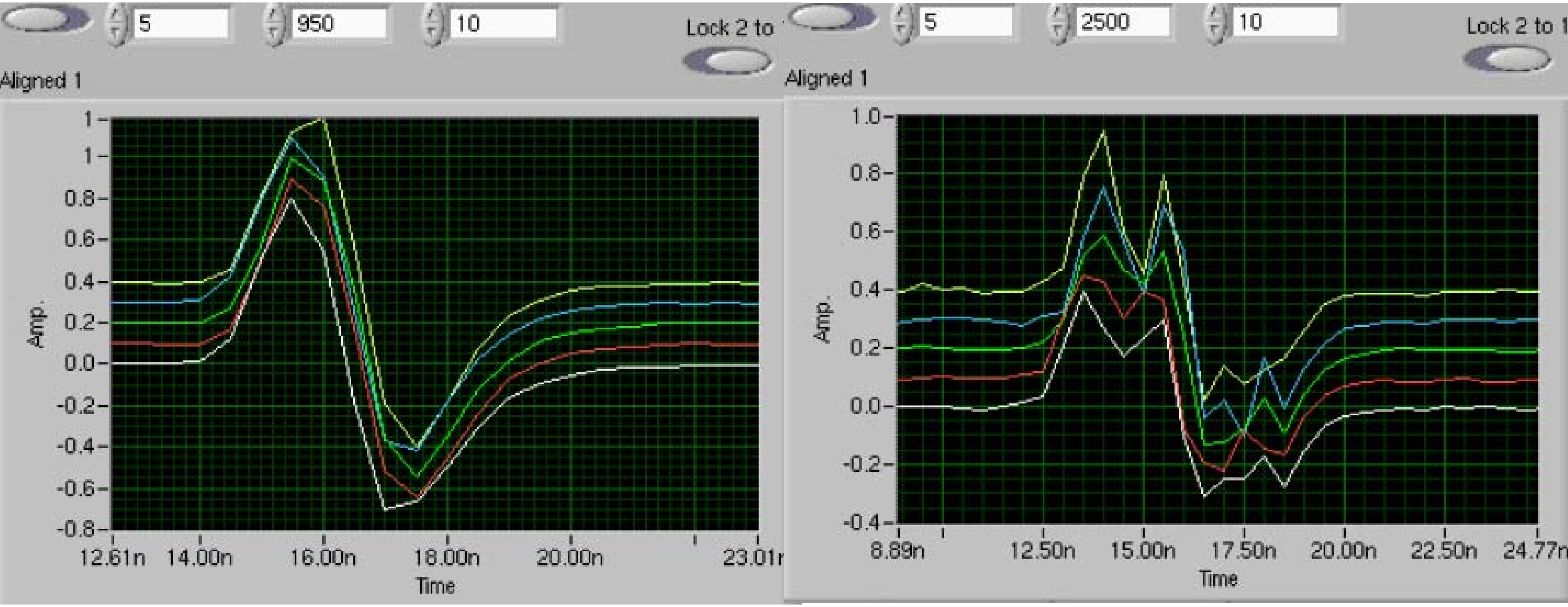
(R. Lee, M. Blaskiewicz)



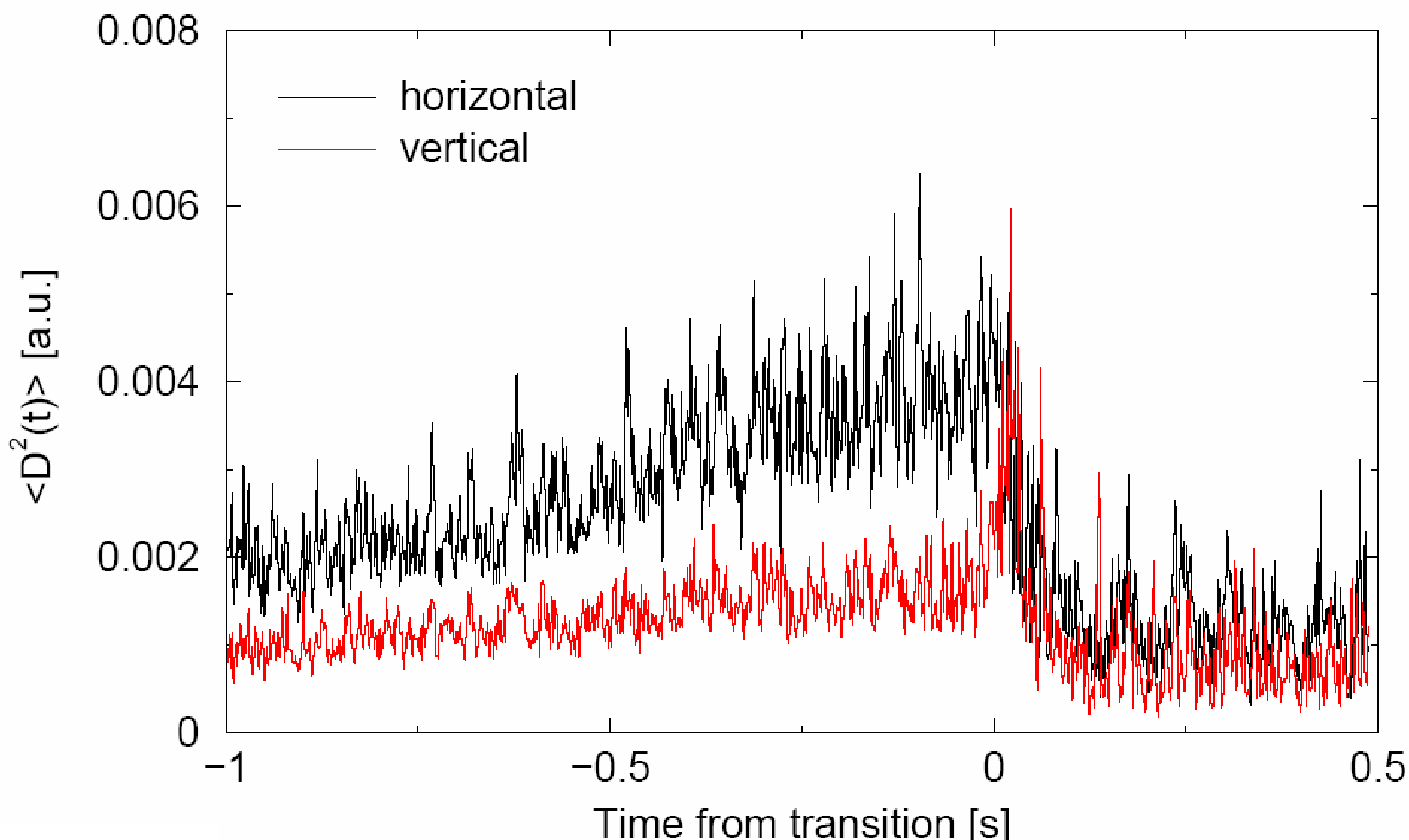
BROOKHAVEN NATIONAL LABORATORY

Button BPM (2)

- The peak position oscillates afterwards
- High frequency structure further develops across the whole bunch corresponding to WCM observation of micro-bunching



Instability seen on button BPM

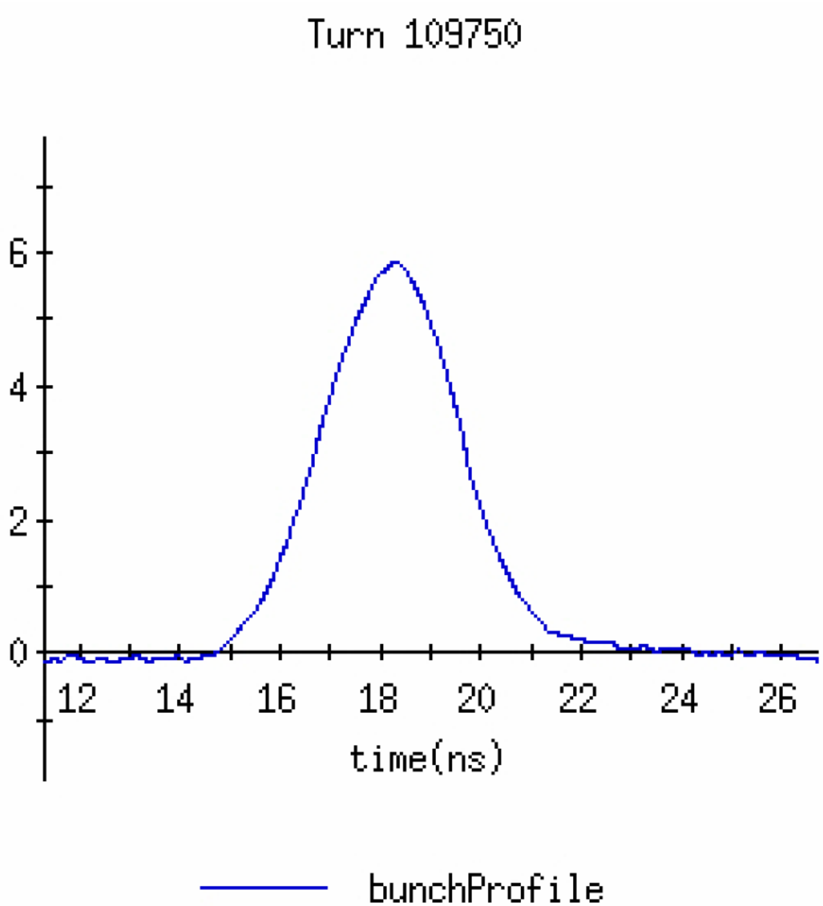


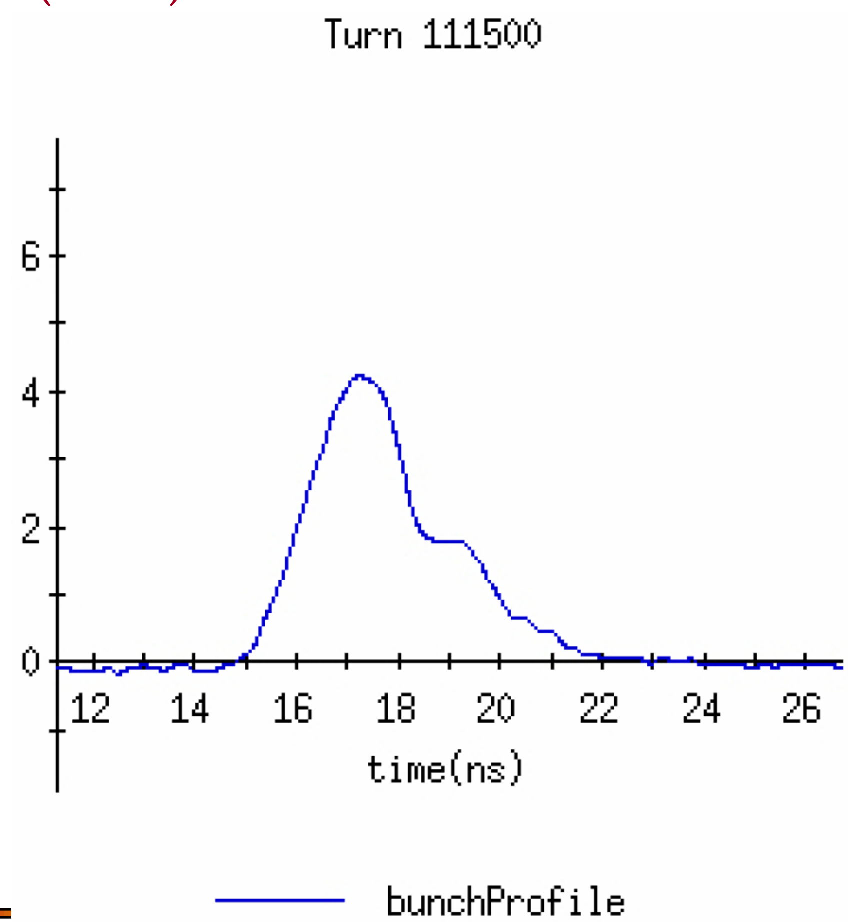
(M. Blaskiewicz)

Figure 6: Mean square of the difference displacement measured by the "button" BPM sampling every 0.5 ns.

WCM longitudinal profiles (1)

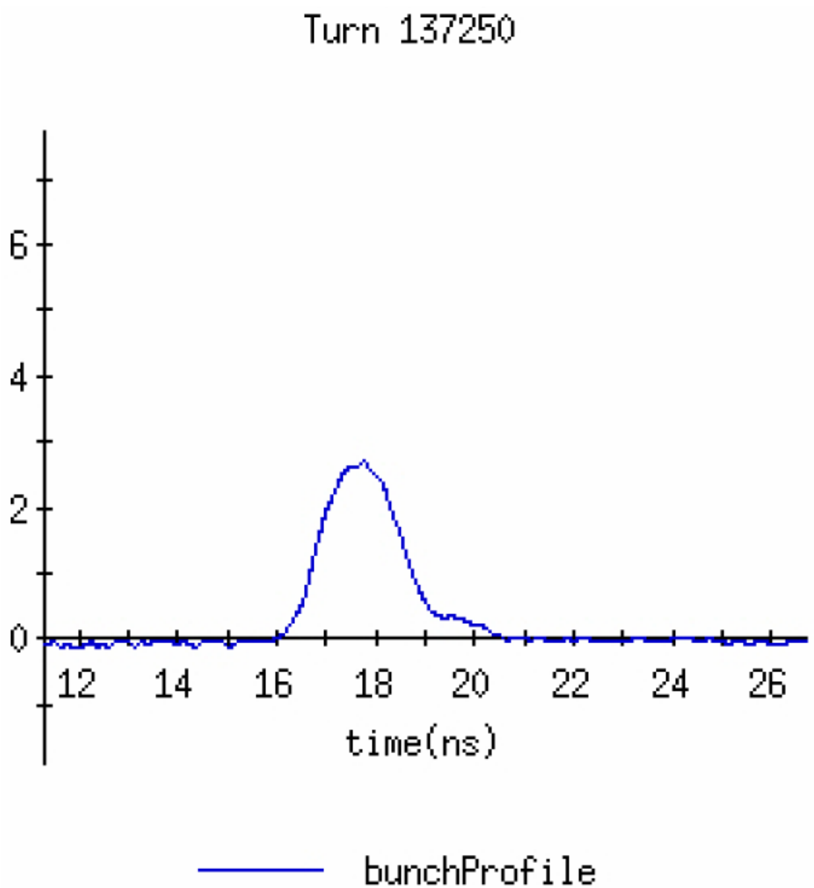
- During unstable period, high frequency (~400 MHz) structure developed on the trailing edge of the bunch #40
- Trailing edge beam break-up (BBU)

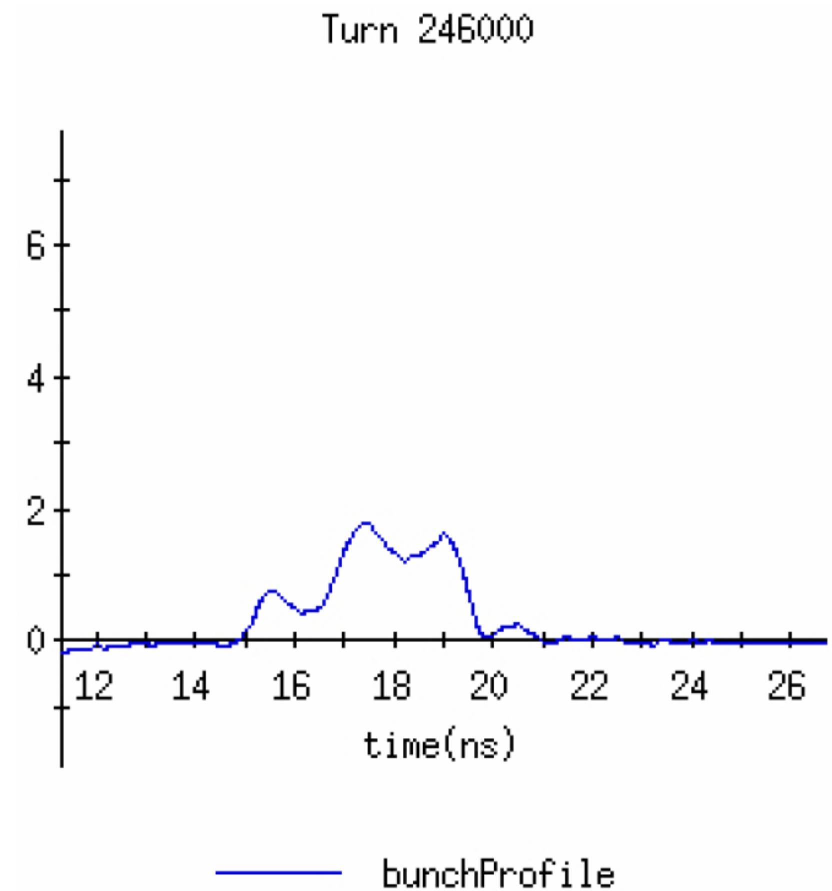




WCM longitudinal profiles (2)

- The trailing edge structure lasts for longer than 50 ms
- About 1.7 seconds later, micro-bunching occurs across the whole bunch





Beam loss at the bunch trailing edge

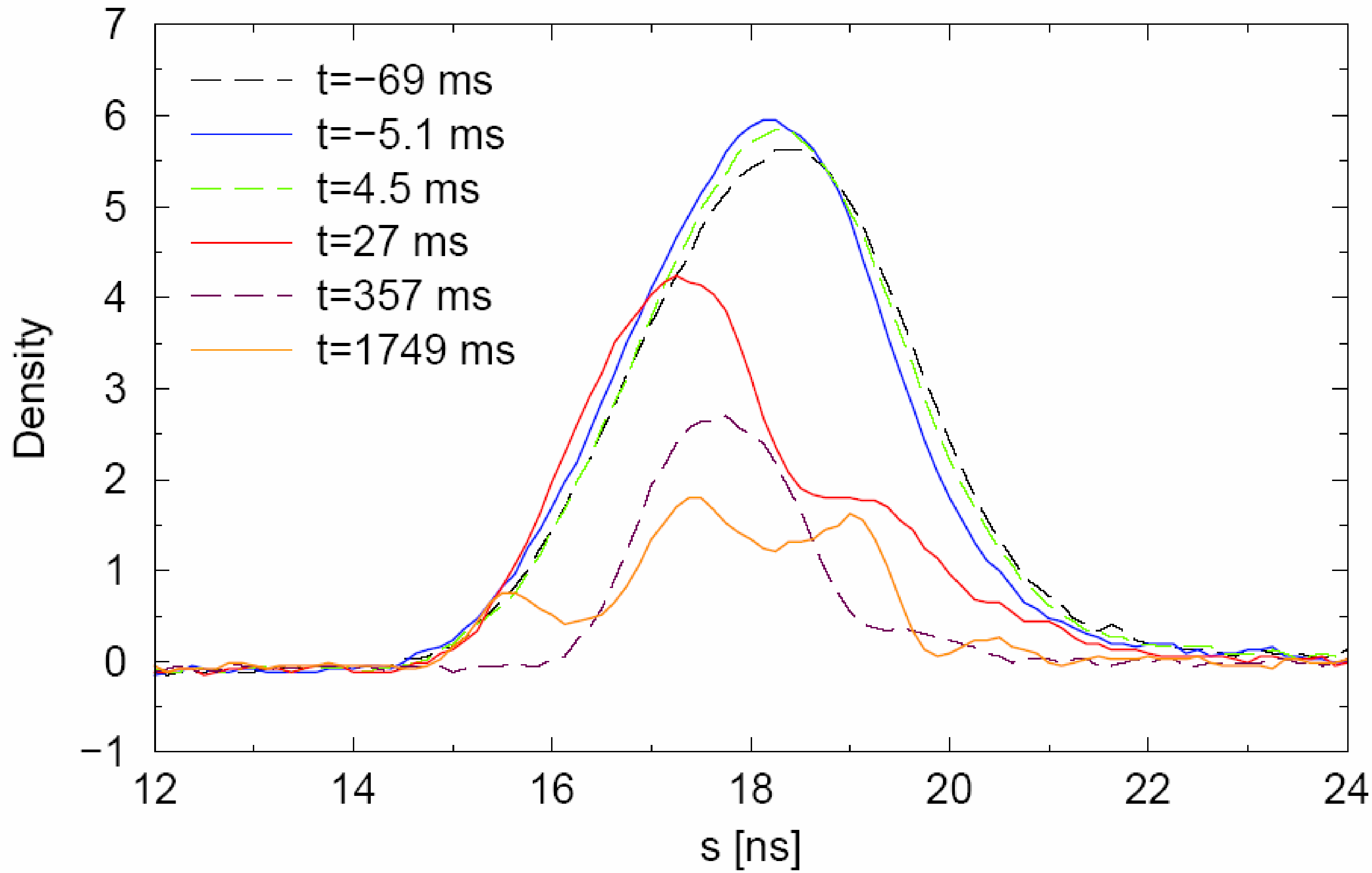


Figure 9: Evolution of the longitudinal profile upon the beam loss near γ_T with V_{rf}=300 kV and $b_{oct} = -4$ unit.

BROOKHAVEN NATIONAL LABORATORY

Transverse emittance growth

- When beam loss is relatively moderate, emittance growth shows bunch train dependence
- It is difficult for IPM to work near transition (electron? Loss/pressure/background?)

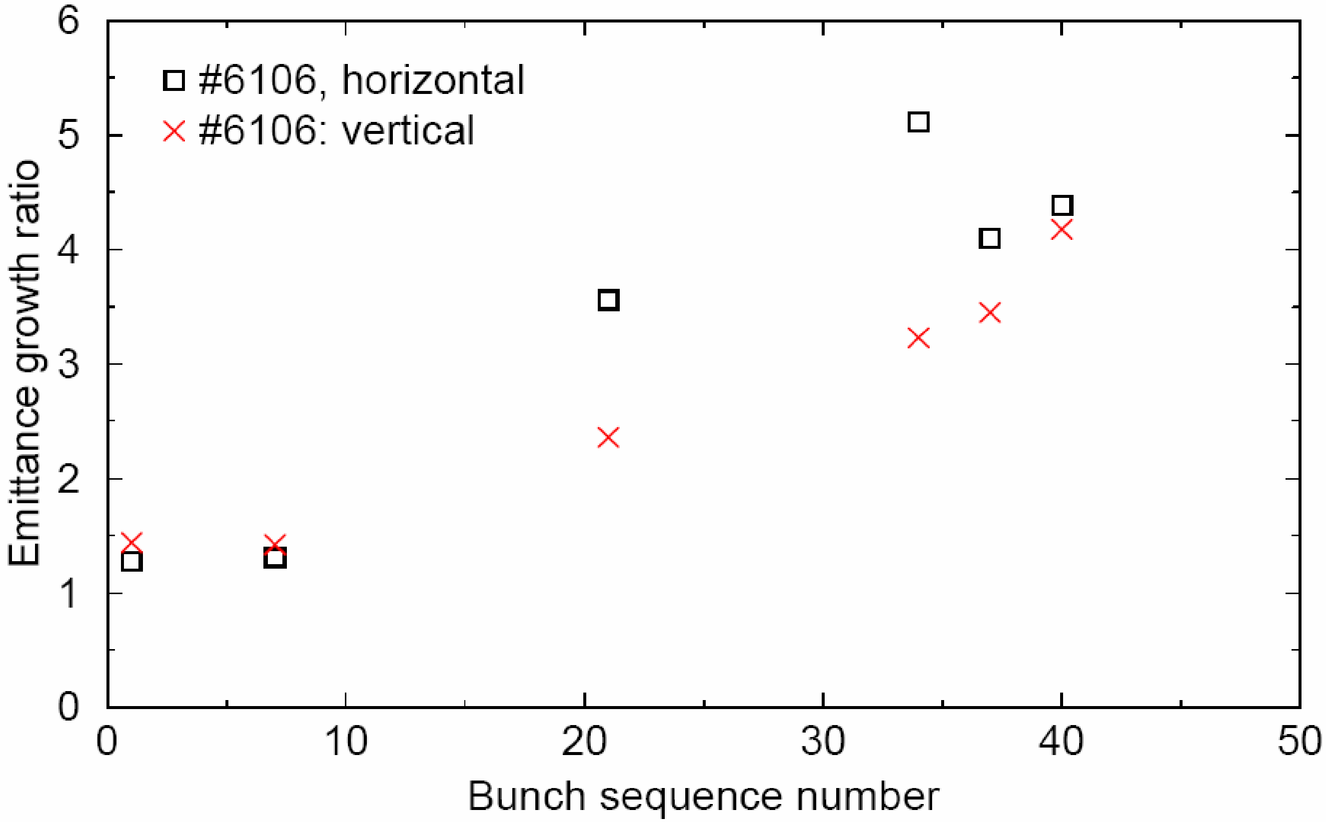


Figure 8: Bunch train dependence of the beam emittance growths at γ_T with V_{rf}=100 kV and $b_{oct} = -4$ unit.

RF voltage dependence (strong)

- Lower RF voltage: no coherence; lower beam loss; lower e-flux
- RF manipulation can possible cure the problem!

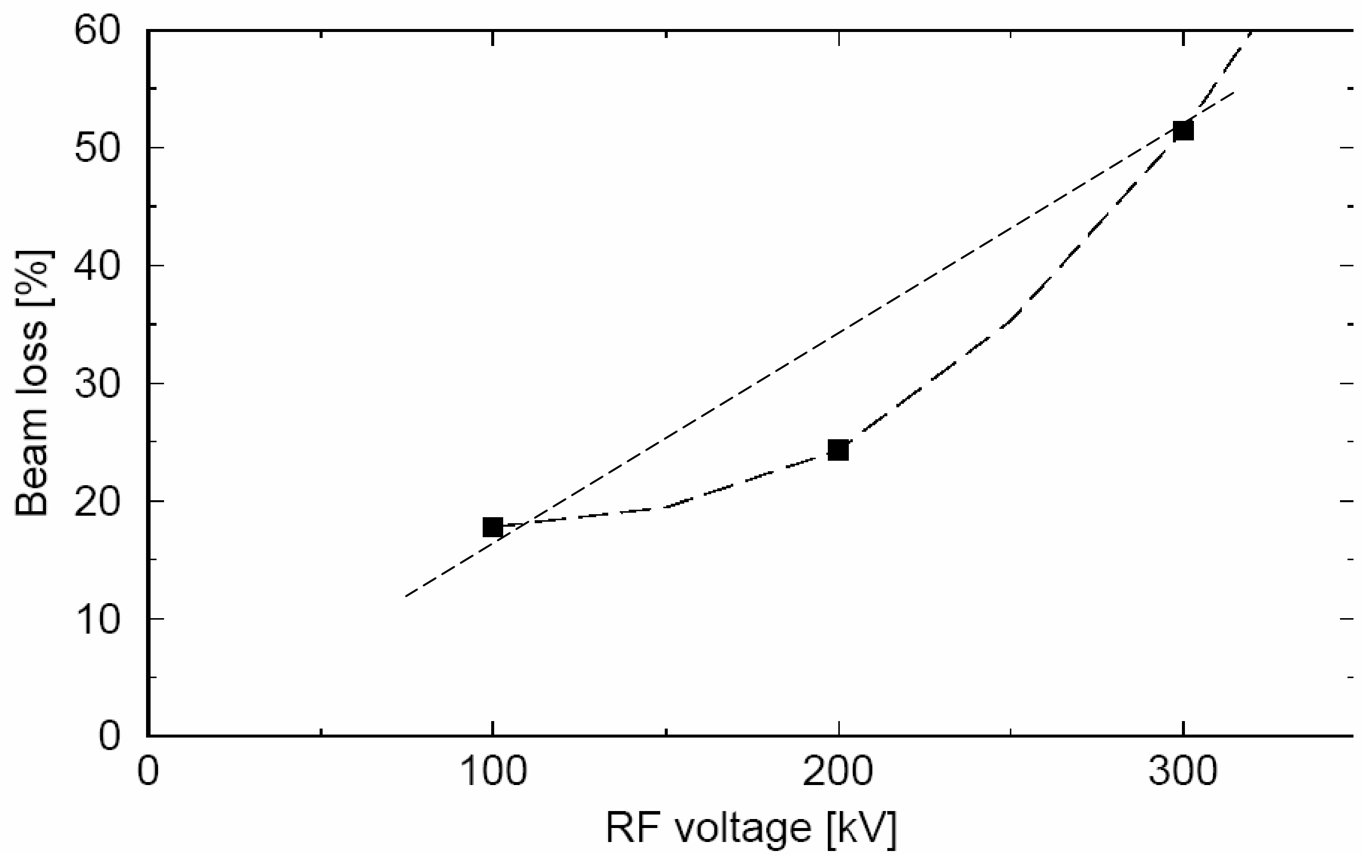


Figure 4: Average beam loss at transition as a function of the RF voltage with $b_{oct} = -3$ unit.

Octupole dependence (weak)

- Higher octupole strength: lower loss, lower coherence

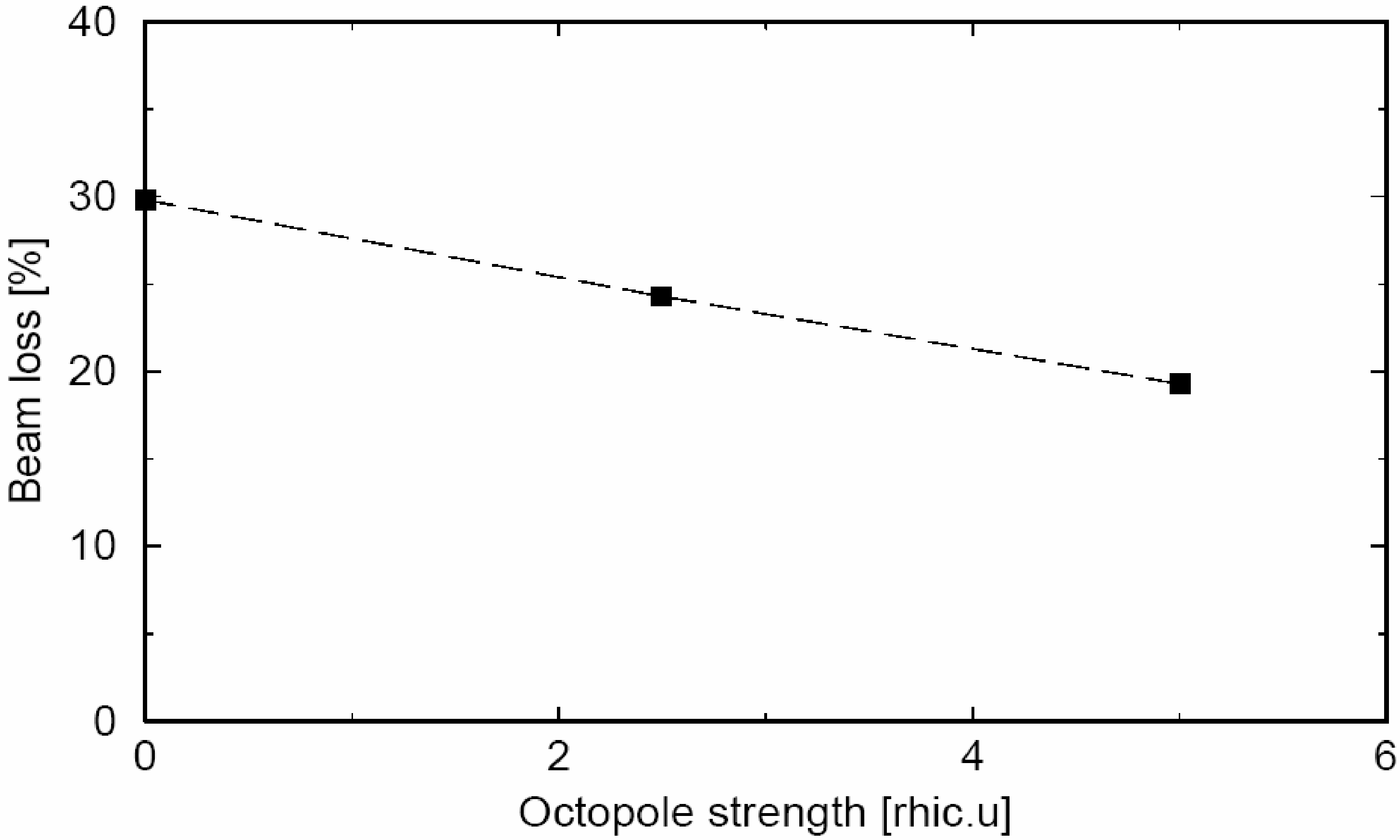


Figure 7: Average beam loss at transition as a function of the octupole magnet strength $|b_{oct}|$ with $V_{rf} = 200$ kV.

Mitigation

- NEG coating/solenoid in warm section
  - 30% solution
- RF manipulation
  - RF voltage choice
  - Dual-harmonic RF
  - Induction RF
- Damping enhancement
  - Octupoles
  - Fast chromaticity jump at transition?
  - Fast, wide-band damper?
- Multiple bunch gaps?
- Beam conditioning?

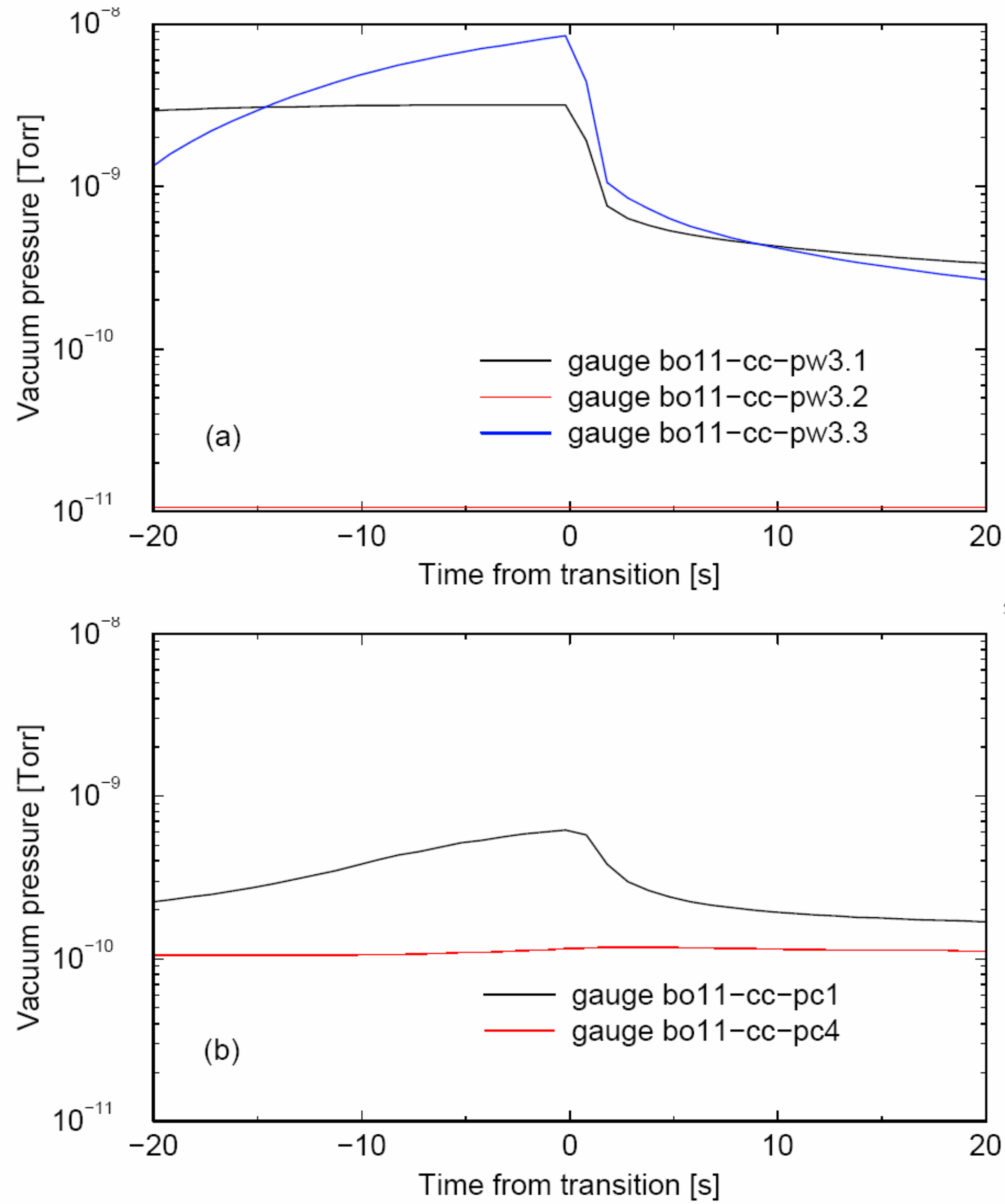
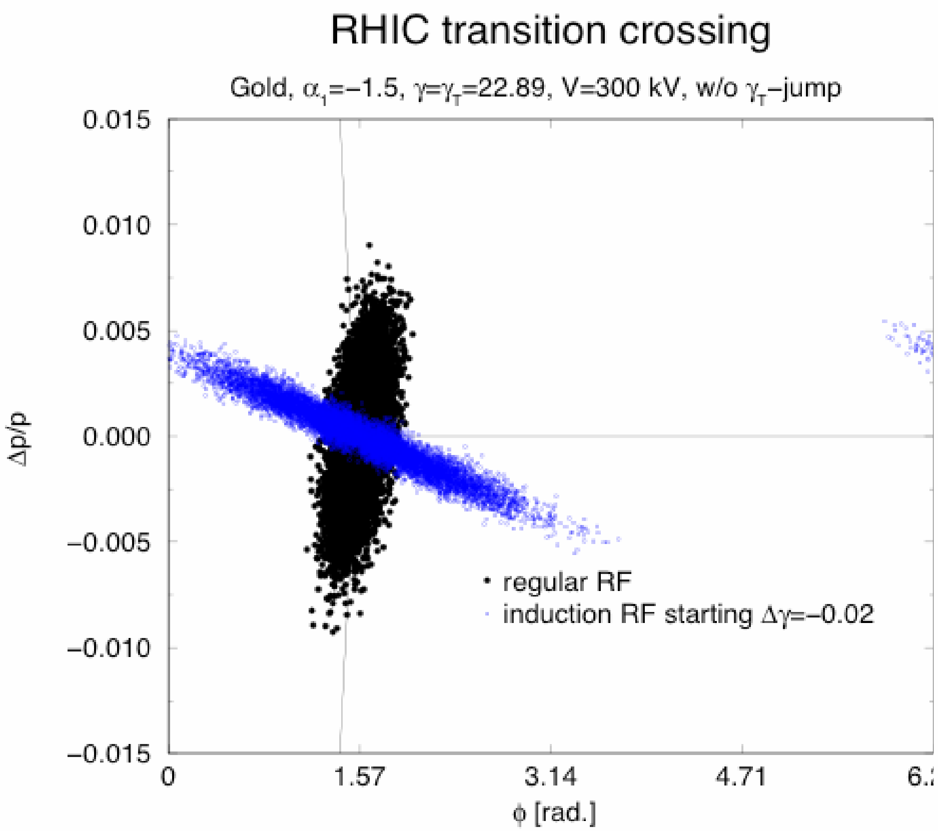
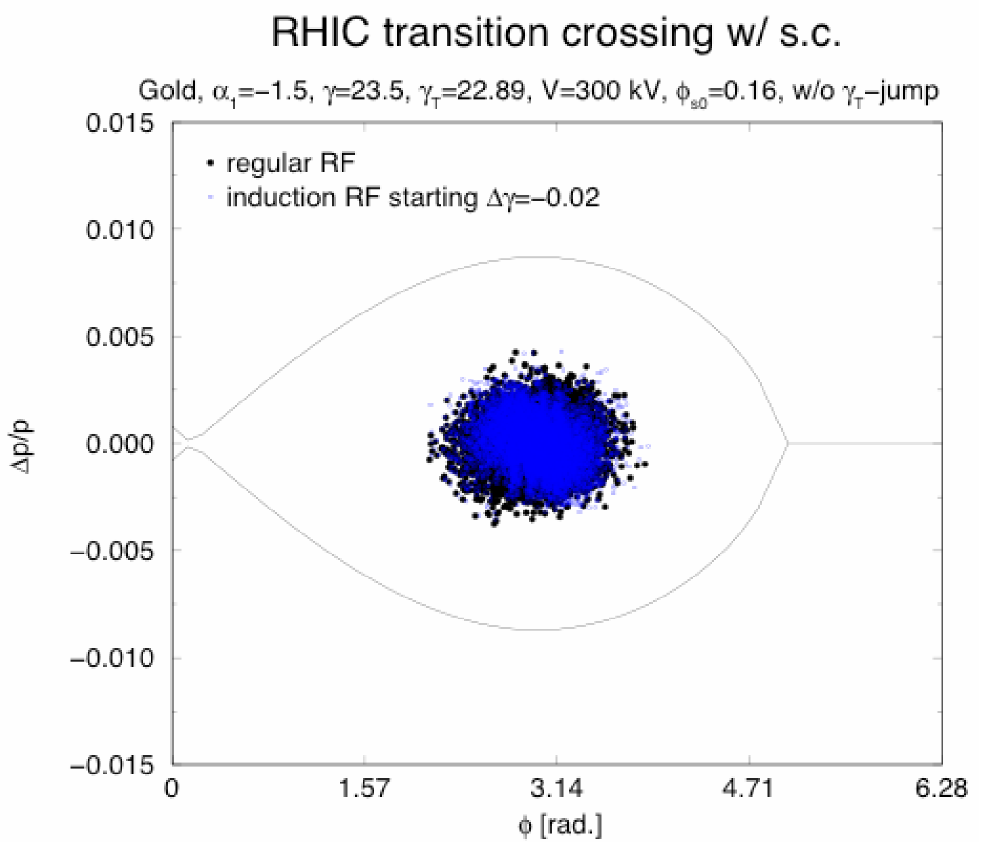


Figure 11: Vacuum pressure rise in the (a) warm and (b) cold region of the ring. Pressure on gauge bo11-cc-pw3.2 located between the two NEG-coated pipes does not rise.

Focusing-free transition crossing

- Replacing regular RF with FFTC induction cavity at transition
- May need to compensate lattice linearity to be reversible





BROOKHAVEN NATIONAL LABORATORY

Open questions

- Why even the first bunch in the train suffers a beam loss much higher than the nominal?
  - One possibility is the multipacting-related gas scattering. More detailed logging of the vacuum pressure (every 0.1 s instead of 1s) may clarify the mechanism.
- Does the instability alone causes more than 70% beam loss in 0.1 s? what are the principle instability modes? and why beam loss and the transverse instability occur only after but not before transition?
  - A possible explanation yet to be verified is a sizable tune shift due to e-cloud coupled with a transition-jump lattice close to resonance. e-detector data needs to be logged in finer steps (1 ns instead of 10 ns) to explore e-cloud generation within each single bunch.

Comments

- Set up PLL tune measurement on the bunch train head (1/3) and tail (1/3). Al stated that there is a big shift in tune between the head and tail of the 40-bunch train though many of us did not understand the plot yet.
- The e-detector logging could be more detailed, 1 ns instead of 10 ns. That way we could have detailed e-signal within a bunch t compare rising/trailing edge difference.
- The IPM manager stopped about 15 sec before transition even though Roger/Steve were present. Perhaps the electron signal was too strong for IPM.
- The M-turn BPM did not show meaningful signal according to Todd.
- The vacuum pressure 100 ms logging data was absent (not triggered?)
- The Artus tune measurement along the bunch train did not show observable tune shift at injection even though Todd twice ran his script.
- We should have used 200 kV RF voltage at transition instead of 300 kV. Last time when using 200 kV at injection through transition (fill #6250) a mysterious instability at injection was correlated to electron cloud (bunch train dependent beam loss, correlation to e-flux, coherence). But if we start with 300 kV and lower to 200 kV that would work.
- We could also measure bunch train tune with PLL at injection but didn't have time.
- We could later calibrate coherence signal with AC dipole.

Conclusion

- Electron cloud is a serious obstacle on RHIC's upgrade path
- Mitigation is not trivial, e.g. using induction RF across transition
- More simulation and study is needed, especially on electron-ion interaction

PLL tune measurement

- Tune tracked well through transition, but
- Tracked H-plane of head and V-plane of tail of the bunch train